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Research Paper

Effects of high voltage pulsed current (HVPC) on pain, inflammation, and mobility in patients with anterior knee pain: A randomized clinical trial

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ABSTRACT

Anterior knee pain is a prevalent musculoskeletal condition that limits function and quality of life. High-voltage pulsed current (HVPC) has been proposed as an adjunct therapy for reducing pain and effusion and improving mobility; however, its clinical effectiveness remains unclear. This randomized clinical trial investigated the impact of HVPC on pain, knee effusion, and range of motion in patients with anterior knee pain. Ninety-six individuals were screened, and 86 were randomized to receive either HVPC plus a routine physiotherapy program (including infrared radiation, transcutaneous electrical nerve stimulation (TENS), and strengthening exercises; n = 43) or routine physiotherapy alone (n = 43). After attrition, 75 participants completed the study. Pain intensity was measured using a visual analogue scale (VAS). Knee effusion was assessed by measuring the circumference with a tape at the infra-, mid-, and supra-patellar levels. Range of motion was evaluated using goniometry. Assessments were conducted at baseline, after five treatment sessions, after ten sessions, and at one-month follow-up. Both groups demonstrated significant improvements over time in pain, effusion, and range of motion (all $p<0.001$). However, mixed two-factor analysis of variance revealed no significant group × time interaction for any outcome (pain $p=0.61$; infra-patellar effusion $p=0.37$; mid-patellar effusion $p=0.50$; supra-patellar effusion $p=0.38$; flexion $p=0.09$; extension $p=0.08$). These findings suggest that adding HVPC to routine physiotherapy does not provide additional clinical benefit. Routine physiotherapy, including TENS and exercise, remains an effective treatment option for managing anterior knee pain.

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1. Introduction

Anterior knee pain is one of the most common musculoskeletal problems, accounting for 25% of knee injuries in sports [1]. The leading causes of it include trauma, overuse, and malalignment of lower extremities, patella mal-tracking, idiopathic chondromalacia, and psychological factors [2]. The most common symptom in subjects with anterior knee pain is pain caused by prolonged sitting in a bent knee position, walking up and down stairs, and running. The patient cannot localize the pain and often reports it in the anterior part of the knee [2,3].

Another symptom of anterior knee pain is soft tissue inflammation [1]. About 90% of patients with anterior knee pain experience moderate to severe effusion. In many patients with knee effusion, the rehabilitation process is hindered by swelling, resulting in a delay in returning to functional tasks [4-6]. Several studies have investigated the analgesic methods in patients with anterior knee pain, and less attention has been paid to reducing effusion and increasing range of motion (ROM) along with pain reduction [4]. Although most studies have evaluated the degenerative effects of knee effusion on various aspects of knee function, little research has been conducted on the impact of therapeutic programs on reducing effusion [1]. Some of the interventions used to relieve knee pain and effusion include: bandage, limb elevation, laser therapy, medication, and electrical stimulation such as transcutaneous electrical nerve stimulation (TENS), HVPC, and interferential current [7-9].

TENS is a routine noninvasive modality used in physiotherapy for pain relief under several conditions [10]. Most studies on TENS have focused on its analgesic effects, with few investigating the efficacy of TENS on joint edema and inflammation [10,11]. HVPC has been used for many years (its devices have been available since 1940) to control pain and edema [12]. HVPC may be effective in reducing effusion due to polarity. HVPC is used in specific clinical disorders, including wound healing, pain reduction, and reduction of effusion [13]. However, TENS and HVPC are two commonly used electrophysical modalities that are routinely applied to patients with knee pain. The mechanisms and efficacy of these modalities may differ in these patients [10,13]. The primary objective of this study was to assess the impact of HVPC on pain, knee effusion, and mobility in comparison to routine physiotherapy in patients with anterior knee pain.

2. Materials and Methods

2.1 *Study Design and Participants*

This randomized clinical trial screened 96 patients with anterior knee pain, of whom 86 met the eligibility criteria (15 men, 71 women) and were randomized; data from 75 participants were finally analyzed. Patients were recruited by convenience sampling from the outpatient clinic; after screening for eligibility, they were randomly assigned in a 1:1 ratio to either the HVPC or control group with allocation concealment. Patients and outcome assessors were blinded to group allocation. Physiotherapists who delivered the interventions were necessarily aware of treatment assignment. Inclusion criteria were age 20–60 years and anterior knee pain with effusion confirmed by orthopedic examination. Exclusion criteria included advanced osteoarthritis, fractures, prior knee/hip surgery, complete ligament or meniscus rupture, infection, referred pain, recent physiotherapy, malignancy, diabetes, and rheumatologic diseases. Based on a pilot study, the required sample size was estimated to be 40 per group ($\alpha = 0.05$, power = 80%).

2.2 *Outcome measures*

2.2.1 *Pain assessment*

The VAS was used to assess pain severity, and the patient was asked to express the mean pain severity on a scale of 0 to 10, where 0 represented no pain and 10 represented the worst pain experienced by the participant. Knee effusion measurement. The patient was sitting. The knee was in the extension position, so that the pillow was not below the knee. Then, the apex of the patella, the mid-patella, and the supra-patellar area were marked, and knee circumference was measured with a flexible tape according to the standardized procedure described by Ghiasi et al. [14].

2.2.2 *Knee range of motion measurement*

Knee flexion and extension ROM were measured in the supine position using a universal goniometer. Landmarks included the greater trochanter, lateral femoral condyle, and lateral malleolus. For flexion, with a towel under the ankle, patients actively bent their knee; for extension, they extended their knee while supine. The goniometer's fixed arm was aligned with the femur, the axis over the lateral femoral condyle, and the moving arm with the fibula. Hyperextension was recorded as negative. Measurements were taken at four time points: baseline (T1), after five sessions (T2), after ten sessions (T3), and one-month follow-up (T4) [15].

2.3 *Therapeutic interventions*

2.3.1 *Control group*

The routine physiotherapy program included infrared therapy, TENS, and quadriceps strengthening exercises.

1. Infra-red (IR) radiation for 20 minutes: The IR light bulb was placed at a distance of 50 cm from the knee of the subjects, and the patient felt mild heat [8,9].
2. Brief TENS for 20 minutes: 4 electrodes of the TENS device were used on both sides of the knee. The used frequency varied from 3 to 120 Hz, and the patient felt the electrical current at both sensory and motor levels.

3. Quadriceps muscle strengthening exercises, including four types of exercise, were also performed from the third session to the tenth session, twice daily.

2.3.2 *HVPC group*

All interventions in the control group were applied in the HVPC group. Only HVPC was added to the usual methods. Four-electrode devices were used in this method, with the electrodes arranged in a proximal-to-distal configuration. The polarity was alternated at each session to capture the theoretical advantages of both cathodal and anodal stimulation (negative polarity for edema reduction, positive polarity for tissue repair). The current at 30 pps was maintained on the patient's knee for 20 minutes, during which time the patient experienced the minimum sensation of electrical stimulation.

2.4 *Statistical analysis*

Data normality was assessed using the Shapiro-Wilk test. An independent t-test was used to compare the demographic and quantitative variables between the two groups before treatment and between-group comparisons. Also, the chi-square test was used to compare categorical variables.

A mixed two-factor Analysis of Variance (ANOVA) (2*4) was used to examine the main and interaction effects of the two factors, group and time, on the dependent variables. The Bonferroni post hoc test (sphericity/Mauchly test) was used to compare the mean differences between the two groups.

3. Results

During follow-up, five participants in the control group and six participants in the HVPC group were lost to follow-up or discontinued the intervention. Therefore, data from 75 participants (37 control, 38 HVPC) were included in the final analysis (Figure 1).

Baseline demographic and clinical characteristics of the analyzed participants (38 in the HVPC group and 37 in the control group) were comparable, with no significant differences between groups (Table 1).

Seventy-five participants (38 in the HVPC group and 37 in the control group) completed the study. Both groups showed significant improvements over time in pain (VAS), infrapatellar, midpatellar, and suprapatellar effusion, as well as knee flexion and extension (all time effects, $p < 0.001$).

However, mixed two-factor ANOVA showed no significant group × time interactions for any outcome (pain $p = 0.61$; infra-patellar effusion $p = 0.37$; mid-patellar effusion $p = 0.50$; supra-patellar effusion $p = 0.38$; flexion $p = 0.09$; extension $p = 0.08$), indicating that adding HVPC to routine physiotherapy did not provide additional benefit. Bonferroni post-hoc comparisons confirmed significant within-group changes over time but no significant between-group differences at any individual time point (all $p > 0.05$) (Table 2 and Figure 2).

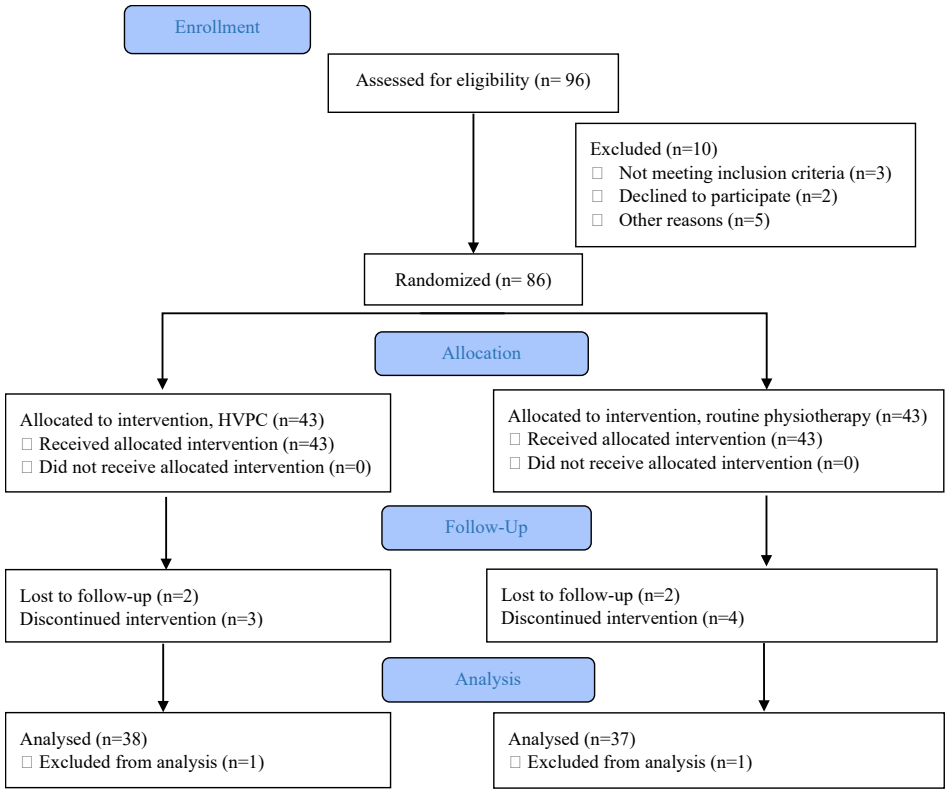

Figure 1. Assessment and treatment process of patients with anterior knee pain.

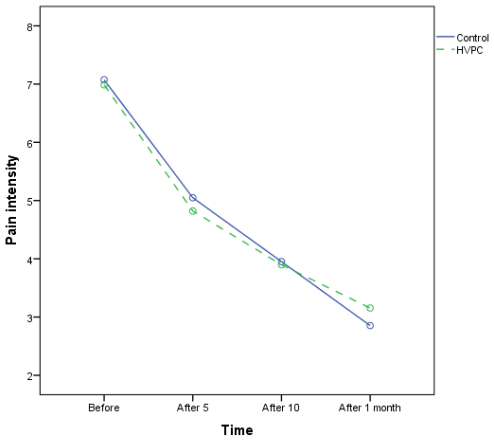

Figure 2. Interaction of group and time on pain intensity in patients with anterior knee pain, HVPC

Table 1. Demographic and clinical features of the subjects in both groups.

Variables	HVPC group (n=38) Mean (SD)/n (%)	Control group (n=37) Mean (SD)/n (%)	P-value
Age (years)	47.85 (13.62)	51.74 (12.94)	0.16
Weight (kg)	76.60 (11.01)	75.43 (14.8)	0.14
Height (cm)	161.15 (8.30)	163.8 (8.44)	0.68
BMI (kg/ m^2)	29.98 (5.62)	28.10 (5.71)	0.10
Pain duration (m)	8.64 (9.36)	8.03 (10.06)	0.10
Gender			
Female	32 (84.2%)	30 (81.1%)	0.74
Male	6 (15.8%)	7 (18.9%)	
Side of pain			
Right	19 (47.5)	17 (41.5)	0.63
Left	21 (52.5)	24 (58.5)	
Primary diagnosis			
PFPS	11 (27.5%)	14 (34.1%)	0.34
DJD I	2 (5%)	3 (3.6%)	0.21
DJD II	14 (35%)	17 (45.2%)	0.53
Soft tissues injury I	3 (7.5%)	5 (12.2%)	0.21
Soft tissues injury II	10 (25%)	2 (4.9%)	0.12

SD, standard deviation; BMI, body mass index; PFPS: patellofemoral pain syndrome, DJD: degenerative joint disease. * Percentages are calculated within each group. Minor discrepancies from 100% are due to rounding.

Table 2. Between-group comparisons of variables: pain, effusion, and range of motion.

Variables, Mean (SD)	T1	T2	T3	T4	P interaction	P main effect	Effect size (Cohen's d)
Pain							
HVPC group	6.96 (1.90)	4.82 (1.99)	4.03 (2.39)	3.25 (2.32)	0.61	Group: 0.96 Time: p<0.001	0.17
Control group	7.07 (1.91)	5.05 (1.77)	3.95 (2.02)	2.85 (2.23)			
P between group	0.79	0.59	0.88	0.39			
Effusion, infra-patellar							
HVPC group	42.16 (3.99)	41.74 (4.15)	41.64 (4.10)	41.34 (4.28)	0.37	Group: 0.96 Time: p<0.001	0.08
Control group	42.56 (4.77)	42.52 (4.61)	41.55 (4.52)	41.69 (3.89)			
P between group	0.68	0.42	0.92	0.69			
Effusion, mid-patellar							
HVPC group	41.17 (3.36)	40.12 (3.37)	40.17 (3.74)	39.65 (3.74)	0.50	Group: 0.73 Time: p<0.001	0.14
Control group	41.17 (3.37)	40.62 (3.91)	40.16 (3.87)	40.20 (3.45)			
P between group	0.99	0.54	0.99	0.48			
Effusion, supra-patellar							
HVPC group	38.85 (4.34)	37.77 (3.17)	38.00 (3.58)	36.57 (5.58)	0.38	Group: 0.91 Time: p<0.001	0.40
Control group	39.30 (3.85)	38.50 (4.09)	38.29 (4.15)	38.08 (3.77)			
P between group	0.62	0.37	0.74	0.15			
ROM, knee flexion							
HVPC group	124.12 (20.47)	129.13 (17.53)	126.25 (31.43)	124.25 (12.23)	0.09	Group: 0.44 Time: p<0.001	0.40
Control group	130.39 (18.74)	133.54 (14.41)	132.44 (15.49)	131.21 (17.33)			
P between group	0.15	0.21	0.26	0.32			
ROM, knee extension							
HVPC group	-2.85 (1.12)	-2.00 (3.88)	-2.50 (4.23)	-0.50 (2.20)	0.08	Group: 0.91 Time: p<0.001	0.05
Control group	-3.15 (1.16)	-1.10 (2.92)	-1.20 (1.56)	-0.36 (2.34)			
P between group	0.08	0.11	0.24	0.79			

SD, standard deviation; T, time; HVPC, high-voltage pulsed current; ROM, range of motion; p, p-value. * Negative values indicate knee hyperextension, consistent with goniometric convention.

4. Discussion

This study demonstrated that HVPC combined with routine physiotherapy did not provide additional benefits compared with physiotherapy alone in terms of pain, effusion, or range of motion in patients with anterior knee pain. These findings are consistent with previous research, which has shown no superiority of HVPC over conventional therapies in musculoskeletal disorders [16–18]. However, most prior studies have focused on ankle sprains rather than anterior knee pain.

Michlovitz et al. reported that both ice and HVPC significantly reduced pain and edema and improved ankle dorsiflexion in acute ankle sprain, with no superiority of HVPC. They attributed the reduction of edema to the electrophoresis effect of the negative pole, which facilitates the movement of proteins and fluids to restore osmotic balance. However, their trial involved only three days of treatment with a smaller sample size and shorter follow-up, which limits comparison with the present study [17]. Sandoval et al. also found no significant differences between HVPC (with either negative or positive polarity) and traditional therapies. However, HVPC with negative polarity produced a slightly greater reduction in edema and recovery. They suggested that combining ice with HVPC might reduce conduction velocity and dampen the stimulation effect [16]. Likewise, Mendel et al. observed no impact of HVPC on recovery in athletes with mild ankle sprains, possibly due to the use of very low current intensities [18]. It is essential to note that findings from animal models cannot be directly generalized to human populations. These variations highlight how treatment parameters and timing (acute vs. chronic phases) influence outcomes. The present trial targeted chronic anterior knee pain, where mechanisms of pain, edema, and restricted mobility differ from those in acute injury, which may explain the absence of HVPC-specific effects. Another essential aspect is polarity. While most studies employed the negative pole to reduce edema [19], our study alternated polarity to capture the theoretical advantages of both poles. Evidence suggests that the anode may stimulate inflammatory responses in acute conditions, whereas the cathode supports proliferation and repair in subacute stages. In chronic inflammation, reversing polarity may help balance ionic shifts and promote tissue regeneration. Despite this rationale, our results did not demonstrate superior outcomes for HVPC. Other factors, such as sensory–motor fiber stimulation and improved circulation, may play a more significant role in managing chronic edema and pain.

HVPC also provides a more comfortable stimulus than other low-frequency currents, such as TENS, due to its lower mean output. However, given the wider availability, lower cost, and comparable effectiveness of TENS, physiotherapy with or without TENS remains a practical and sufficient intervention for anterior knee pain. More trials with larger populations, varied current parameters, and longer follow-up periods are needed to clarify whether HVPC may be beneficial in specific subgroups or conditions. It is also important to note that both groups performed quadriceps strengthening exercises, which are well established as a core intervention for anterior knee pain. These exercises likely accounted for much of the improvement observed in pain, effusion, and mobility, and may have overshadowed any potential additive effect of HVPC.

This study has several limitations: (a) knee effusion was assessed by tape measurement rather than imaging techniques such as ultrasonography or MRI; (b) no untreated control group was included to track the natural course of the condition; (c) treatment time per session was slightly longer in the HVPC group; (d) patients were not stratified by baseline pain or effusion severity, which may have influenced responsiveness; and (e) Knee extension values were recorded as negative when hyperextension was present. Although this is consistent with goniometric convention, it may appear counterintuitive to some readers and partly explains the relatively high standard deviations observed in extension measurements.

This randomized clinical trial demonstrated that both HVPC combined with physiotherapy and physiotherapy alone significantly reduced anterior knee pain, decreased effusion, and improved mobility. However, HVPC did not confer additional benefits beyond those achieved with routine physiotherapy, which already included TENS, infrared therapy, and strengthening exercises. Routine physiotherapy, therefore, remains a safe, effective, and sufficient treatment for anterior knee pain. Future research with larger samples, longer follow-up periods, and stratification of patients by baseline severity is recommended to determine whether HVPC may offer advantages in specific subgroups or clinical contexts. These findings support the use of routine physiotherapy, including TENS and strengthening exercises, as a first-line management strategy for anterior knee pain in clinical practice.

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Authors' contributions

K E: supervised the project. M S: participated in the study's design and performed the statistical analysis. A N: Collected and interpreted the data. K E and A N: Drafting or revisiting the article critically for important intellectual content. M S and SM ZZ: were the study's project leaders and primary investigators. All authors discussed the results and contributed to the final manuscript.

Conflict of interest

No potential conflict of interest was reported by the authors.

Ethical declarations

This study was approved by the Ethics Committee of Guilan University of Medical Sciences (IR.GUMS.REC.1397.003). All participants provided written informed consent prior to enrollment in accordance with the Declaration of Helsinki. The trial was prospectively registered at the Iranian Registry of Clinical Trials (IRCT20170516034003N3).

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